GEOPHYSICAL RESEARCH LETTERS, VOL. 32, L05707, doi:10.1029/2004GL021316, 2005

Atlantic versus Indo-Pacific influence on Atlantic-European climate

Holger Pohlmann[1,2] and Mojib Latif[3]

Received 23 August 2004; revised 13 November 2004; accepted 31 January 2005; published 4 March 2005.

[1] The influence of the Atlantic and Indo-Pacific oceans on Atlantic-European climate is investigated by analyzing ensemble integrations with the atmospheric general circulation model ECHAM4 forced by anomalous sea surface temperature and sea ice conditions restricted to the Atlantic (AOGA) and Indo-Pacific (I+POGA) oceans. The forcing from both the Indo-Pacific and Atlantic oceans are important for the generation of the sea level pressure (SLP) variability in the Atlantic region in the boreal winter season. Over the North Atlantic the SLP response in the I+POGA experiment projects on the North Atlantic Oscillation, while it projects on the East Atlantic Pattern in the AOGA experiment. In both experiments (I+POGA and AOGA) a quadrupole-type 500 hPa height anomaly pattern is simulated which emerges from the tropical Pacific and Atlantic oceans, respectively. In boreal summer the influence of the Atlantic Ocean dominates the SLP response in the Atlantic region. The tropical North Atlantic is a key region in forcing the SLP response over the Caribbean Sea in this season. **Citation:** Pohlmann, H., and M. Latif (2005), Atlantic versus Indo-Pacific influence on Atlantic-European climate, *Geophys. Res. Lett.*, *32*, L05707, doi:10.1029/2004GL021316.

1. Introduction

[2] The Atlantic-European climate variability is dominated by the North Atlantic Oscillation (NAO). The NAO is a seasaw in sea level pressure (SLP) with centers over the Azores and Iceland. The influence of the NAO on the North Atlantic is widely accepted [e.g., *Visbeck et al.*, 1998]. The projection of the NAO onto North Atlantic sea surface temperature (SST) is a tripole pattern on interannual timescales [e.g., *Marshall et al.*, 2001]. The correlation is highest when the tripole SST index lags the NAO by about one month indicating an atmospheric influence on the ocean [*Deser and Timlin*, 1997; *Czaja and Frankignoul*, 2002]. However, the influence of the ocean on the extratropical atmospheric circulation is not completely understood. A large amount of the variance of the NAO is due to the internal, nonlinear variability of the atmosphere. Experiments with atmosphere general circulation models (AGCMs) forced by a climatological annual cycle of boundary conditions without any interannual variability simulate an NAO with a realistic spatial pattern and spectrum [e.g., *Saravanan*, 1998]. However, AGCM ensemble simulations forced by observed interannually varying SST and sea ice (SI) conditions are able to reproduce a remarkable amount of the observed NAO variability [*Rodwell et al.*, 1999; *Mehta et al.*, 2000; *Latif et al.*, 2000; *Hoerling et al.*, 2001]. These simulations are commonly referred to as Global Ocean Global Atmosphere (GOGA), meaning that observed SST/SI conditions are prescribed globally. To understand the mechanisms of the NAO and to decide whether the NAO is part of a coupled air-sea phenomenon, it is important to know which part of the world's ocean has an impact on the NAO.

[3] *Sutton and Hodson* [2003] show with an optimal detection analysis [*Venzke et al.*, 1999] applied to GOGA-experiments that the mechanisms could be different on different timescales. On multidecadal timescales they find an oceanic influence on the NAO encompassing nearly the whole North Atlantic. This mode shows a strong relationship to the North Atlantic thermohaline circulation in coupled atmosphere-ocean general circulation models (AOGCMs) [e.g., *Latif et al.*, 2004]. *Hoerling et al.* [2001] perform AGCM simulations forced by observed SST/SI conditions restricted to the tropical oceans (Tropical Ocean Global Atmosphere – TOGA). They link the NAO trend over the second half of the 20th century to a progressive warming of the tropics. Specifically, they exclude the tropical Atlantic as the origin of the NAO trend. The results of idealized SST response AGCM experiments, however, are contradictory. Either the Indian Ocean [*Bader and Latif*, 2003], the eastern tropical Pacific [*Schneider et al.*, 2003], or the North Atlantic [*Rodwell et al.*, 2004] is indicated to contribute to the NAO trend. On shorter (interannual) timescales *Sutton and Hodson* [2003] find that the climate of the Atlantic-European region is influenced by the Pacific El Niño/Southern Oscillation (ENSO) phenomenon and also by the Atlantic, especially the tropical North Atlantic. Furthermore, the relative importance of these influences is different during different periods, i.e. the oceanic influence on the NAO is non-stationary [*Raible et al.*, 2001; *Sutton and Hodson*, 2003]. An AGCM comparison shows a dominant influence of tropical North Atlantic SST on the NAO in three of four models during the period 1951–1994 (D. L. Hodson et al., Influence of the oceans on North Atlantic climate variability: A comparison of results from 4 atmospheric GCMs, submitted to *Climate Dynamics*, 2004). However, the dominant influence on the NAO shifts to the tropical Pacific for two of the models in the extended periods 1947–1998 [*Terray and Cassou*, 2002] and 1951–1999 [*Sutton and Hodson*, 2003], respectively. The strong El Niño event in 1997/1998 may cause this alteration. Moreover, *Terray and Cassou* [2002] demonstrate an influence of North Atlantic SST on the NAO with an Atlantic Ocean Global Atmosphere (AOGA) experiment even for the extended period. The AGCM ECHAM4 is used in this

[1]Max-Planck-Institut für Meteorologie, Hamburg, Germany.
[2]Now at Department of Oceanography, Dalhousie University, Halifax, Nova Scotia, Canada.
[3]Leibniz-Institut für Meereswissenschaften, Kiel, Germany.

0094-8276/05/2004GL021316

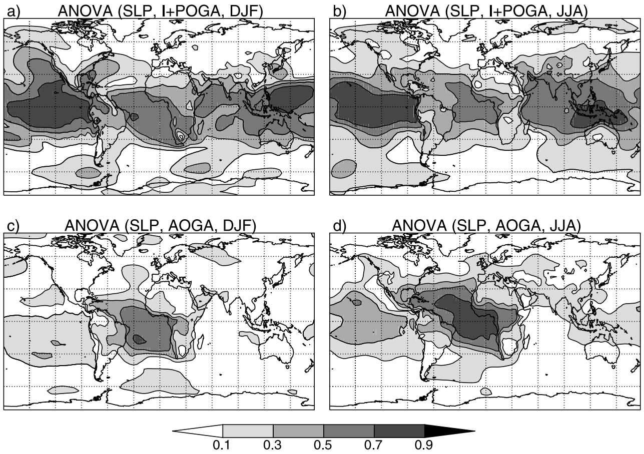

Figure 1. ANOVA values of SLP variability of the I+POGA (top) and the AOGA (bottom) experiments for the boreal winter (DJF) (left) and summer (JJA) (right) seasons. ANOVA values exceeding 0.1 are significant at the 95% level according to an F-test.

study for sensitivity experiments in which the SST forcing is restricted to certain ocean basins to elucidate the Atlantic versus Indo-Pacific influence on Atlantic-European climate.

2. Experiments and Methodology

[4] Three sensitivity experiments with the AGCM ECHAM4 [*Roeckner et al.*, 1996a] are performed: AOGA, I+POGA and GOGA. The AOGA experiment with observed SST/SI forcing restricted to the Atlantic and climatological SST/SI forcing elsewhere is used to determine the role of the Atlantic Ocean for Atlantic-European climate. A counter experiment, I+POGA, with observed SST/SI forcing restricted to the Indo-Pacific and climatological SST/SI forcing elsewhere is used to investigate the influence of the other oceans on Atlantic-European climate. In both experiments, AOGA and I+POGA, the SST/SI forcing is restricted to latitudes north of 30°S. The control experiment, GOGA, with observed SST/SI forcing prescribed globally is performed to test the linearity of the response. For each experiment six ensemble members are performed for the period 1971–1994 at T42-L19 resolution. The forcing is taken from the GISST2.2 dataset [*Rayner et al.*, 1996].

[5] The SLP response of these experiments is investigated with the analysis of variances (ANOVA) and the optimal detection analysis (ODA). The ANOVA yields the ratio of the ocean-forced variance to the total variance of a climate variable. These variances are estimated from an ensemble of integrations. The reader is referred to *Rowell* [1998] for a detailed description of the ANOVA. The second method, the ODA, is a signal-to-noise maximizing EOF algorithm. It yields an estimate of the leading modes of boundary forced variability within an ensemble of integrations. We apply this algorithm to investigate the leading modes (spatial pattern with associated time series) of SST-forced variability in the Atlantic-European region. The reader is referred to *Venzke et al.* [1999] for a detailed description of the ODA.

3. Results

3.1. Atlantic Versus Indo-Pacific Influence

[6] The results of the ANOVA of SLP variability are shown in Figures 1. Highest ANOVA values are present in the tropical and subtropical regions in consistence with other (GOGA) studies [*Rowell*, 1998]. Over the tropical/subtropical Atlantic Ocean the ANOVA values of the I+POGA and AOGA experiments are of similar magnitude in the boreal winter season, which suggests that SST from the Indo-Pacific as well as from the Atlantic may generate the SLP variability. In boreal summer, however, the ANOVA values over the tropical/subtropical Atlantic Ocean are higher for the AOGA experiment than for the I+POGA experiment, which suggests that the influence from the Atlantic Ocean dominates the SLP response in this region.

3.2. Response in the Atlantic-European Region

[7] Figure 2a shows the leading mode of the ODA of the SLP variability restricted to the Atlantic-European region for the I+POGA experiment in boreal winter. The data were detrended prior to the analysis. The SLP response pattern projects on the observed NAO structure. Figure 2b shows the correlations between the time series associated with this mode and the SST field. The correlation pattern features the significant ENSO influence in the I+POGA experiment. The correlation of this mode with the model NAO index, defined as the leading EOF mode of the ensemble mean SLP

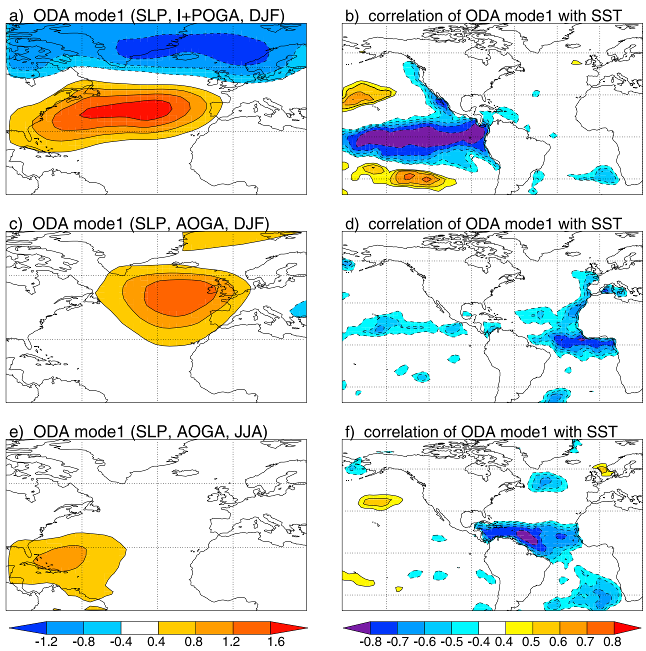

Figure 2. Leading ODA mode of SLP variability [hPa] over the North Atlantic region (left) and correlation values between the corresponding time series and SST (right) for the I+POGA experiment in boreal winter (DJF) (top), the AOGA experiment in boreal winter (DJF) (middle) and the AOGA experiment in boreal summer (JJA) (bottom). Correlation values exceeding 0.4 are significant at the 95% level according to a t-test.

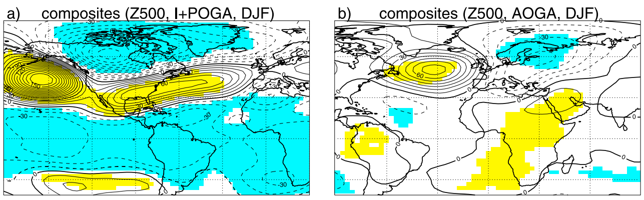

Figure 3. Difference of the Z500 field [gpm] between high and low phases of the leading ODA mode of the (a) I+POGA and (b) AOGA experiments for the boreal winter (DJF) season. The shaded yellow and blue regions indicate significance on the 95% level according to a t-test.

in the Atlantic – European region amounts to 0.74 and with SST averaged over the Niño3 region to −0.93. However, the correlation of the time series of the leading ODA mode with the observed NAO index is not significant. Some evidence for an ENSO influence on Atlantic – European climate exists also from observational studies [*Fraedrich and Müller*, 1992] and an AGCM experiment [*Merkel and Latif*, 2002], but the explained variance is low. The leading mode of the ODA is a monopole in the AOGA experiment in the boreal winter season (Figure 2c) which projects on the East Atlantic Pattern (EAP). The corresponding SST correlation pattern is shown in Figure 2d. In this experiment the leading mode of the ODA projects on tropical eastern Atlantic SST, with strongest (anti-) correlations in the equatorial region. The leading mode of the ODA is also a monopole in the AOGA experiment in the boreal summer season (Figure 2e), which is located over the Caribbean Sea. The corresponding SST correlation pattern (Figure 2f) points to the tropical North Atlantic as a key region in forcing this SLP mode. No significant connection to the North Atlantic in summer was found in the leading ODA mode of the I+POGA experiment.

[8] Figure 3a shows the composites of the 500 hPa geopotential height (Z500) field of the I+POGA experiment for boreal winter averaged over the years with a high (1972, 1974, 1989) minus low (1973, 1983, 1992) leading ODA mode. The composites pattern of the I+POGA experiment projects on the observed PNA quadrupole with an eastward extension into the North Atlantic. Figure 3b shows the composites of the Z500 field of the AOGA experiment for boreal winter averaged over the years with a high (1972, 1977, 1981) minus low (1982, 1988, 1990) leading ODA mode. The pattern is also a quadrupole with centers over the extratropical North Atlantic and the Middle East, and centers of opposite sign over the subtropical North Atlantic and Northeast Europe.

[9] The trend of the ensemble and winter mean Z500 field of the GOGA experiment is the most realistic of all experiments and displays a dipole structure in the Atlantic-European region. The dipole projects onto the NAO pattern, with a decrease over the Arctic and an increase over the subtropical Atlantic and southern Europe (not shown). Over the North Atlantic, the linear combination of the Z500 fields from the I+POGA and AOGA experiments results in a stronger and therefore more realistic dipole than in the experiments with the restricted SST/SI forcing alone (not shown). This result suggests a relevance of both SST/SI from the Atlantic and Indo-Pacific oceans for the NAO trend. However, the Z500 trend is unrealistic (positive) especially in the region of the Aleutian Low in both the GOGA and AOGA experiments and in the sum of the AOGA and I+POGA experiments.

4. Summary and Conclusions

[10] The forcing from both the Indo-Pacific and Atlantic oceans are important for the generation of the SLP variability in the Atlantic region in the boreal winter season. The leading ODA mode of the wintertime SLP variability of the I+POGA experiment, which projects on the NAO, is anticorrelated with ENSO. The teleconnection between these two climate phenomena involves the PNA, with an eastward extension into the North Atlantic. A strong sensitivity of the NAO to tropical Pacific SST is also present in the coupled AOGCM ECHAM4/OPYC [*Roeckner et al.*, 1996b]. Therefore, the strong sensitivity to tropical Pacific SST in the I+POGA experiment does not seem to be caused by a lack of feedbacks from the ocean to the atmosphere. The teleconnection between ENSO and the NAO in the I+POGA experiment in the boreal winter season can be explained by an El Niño-related weakening of the North Atlantic mean meridional pressure gradient and a southward shift of the North Atlantic storm track [*Merkel and Latif*, 2002]. In the absence of varying Indo-Pacific SST, a quadrupole Z500 anomaly response pattern emerges in boreal winter in the AOGA experiment. This pattern is spatially shifted to the PNA and extends over the North Atlantic – Eurasian – African region. In boreal summer, however, the influence of the Atlantic Ocean dominates the SLP response over the North Atlantic. SST variability in the tropical North Atlantic drives the SLP response over the Caribbean Sea in this season.

[11] **Acknowledgments.** We thank Jürgen Bader, Daniel Hodson, Noel Keenlyside, Ute Merkel and Erich Roeckner for the discussion of our results and comments on this paper. This work was supported by the European Union project PREDICATE, and the German Ministry for Education and Research (BMBF) project DEKLIM.

References

Bader, J., and M. Latif (2003), The impact of decadal-scale Indian Ocean sea surface temperature anomalies on Sahelian rainfall and the North Atlantic Oscillation, *Geophys. Res. Lett.*, *30*(22), 2169, doi:10.1029/2003GL018426.

Czaja, A., and C. Frankignoul (2002), Observed impact of Atlantic SST anomalies on the North Atlantic Oscillation, *J. Clim.*, *15*, 606–623.

Deser, C., and M. S. Timlin (1997), Atmosphere-ocean interaction on weekly timescales in the North Atlantic and Pacific, *J. Clim.*, *10*, 393–408.

Fraedrich, K., and K. Müller (1992), Climate anomalies in Europe associated with ENSO extremes, *K. Climatol.*, *12*, 25–31.

Hoerling, M., J. Hurrell, and T. Xu (2001), Tropical origins for recent North Atlantic climate change, *Science*, *292*, 90–92.

Latif, M., K. Arpe, and E. Roeckner (2000), Oceanic control of decadal North Atlantic sea level pressure variability in winter, *Geophys. Res. Lett.*, *27*, 727–730.

Latif, M., et al. (2004), Reconstructing, monitoring, and predicting multi-decadal-scale changes in the North Atlantic thermohaline circulation with sea surface temperature, *J. Clim.*, *17*, 1605–1614.

Marshall, J., Y. Kushnir, D. Battisti, P. Chang, A. Czaja, R. Dickson, J. Hurrell, M. McCartney, R. Saravanan, and M. Visbeck (2001), North Atlantic climate variability: Phenomena, impacts and mechanisms, *Int. J. Climatol.*, *21*, 1863–1898.

Mehta, V., M. Suarez, J. Manganello, and T. Delworth (2000), Oceanic influence on the North Atlantic Oscillation and associated Northern Hemisphere climate variations: 1959–1993, *Geophys. Res. Lett.*, *27*, 121–124.

Merkel, U., and M. Latif (2002), A high resolution AGCM study of the El Niño impact on the North Atlantic/European sector, *Geophys. Res. Lett.*, *29*(9), 1291, doi:10.1029/2001GL013726.

Raible, C. C., U. Luksch, K. Fraedrich, and R. Voss (2001), North Atlantic decadal regimes in a coupled GCM simulation, *Clim. Dyn.*, *18*, 321–330.
Rayner, N. A., E. B. Horton, D. E. Parker, C. K. Folland, and R. B. Hackett (1996), Version 2.2 of the global sea-ice and sea surface temperature data set, 1903–1994, *Clim. Res. Tech. Note CRTN 74*, Hadley Cent., Met Off., Bracknell, UK.
Rodwell, M., D. Rowell, and C. Folland (1999), Oceanic forcing of the wintertime North Atlantic Oscillation and European climate, *Nature*, *398*, 320–323.
Rodwell, M. J., M. Drevillon, C. Frankignou, J. W. Hurrell, H. Pohlmann, M. Stendel, and R. T. Sutton (2004), North Atlantic forcing of climate and its uncertainty from a multi-model experiment, *Q. J. R. Meteorol. Soc.*, *130*, 2013–2032.
Roeckner, E., K. Arpe, L. Bengtsson, M. Christoph, M. Claussen, L. Dümenil, M. Esch, M. Giorgetta, U. Schlese, and U. Schulzweida (1996a), The atmospheric general circulation model ECHAM-4: Model description and simulation of present-day climate, *MPI Rep. 218*, Max Planck Inst. for Meteorol., Hamburg, Germany.
Roeckner, E., J. M. Oberhuber, A. Bacher, M. Christoph, and I. Kirchner (1996b), ENSO variability and atmospheric response in a global coupled atmosphere-ocean GCM, *Clim. Dyn.*, *12*, 737–754.
Rowell, D. P. (1998), Assessing potential seasonal predictability with an ensemble of multidecadal GCM simulations, *J. Clim.*, *11*, 109–120.
Saravanan, R. (1998), Atmospheric low-frequency variability and its relationship to midlatitude SST variability: Studies using the NCAR Climate System Model, *J. Clim.*, *11*, 1386–1404.
Schneider, E. K., L. Bengtsson, and Z.-Z. Hu (2003), Forcing of Northern Hemisphere climate trends, *J. Atmos. Sci.*, *60*, 1504–1521.
Sutton, R. T., and D. L. R. Hodson (2003), Influence of the ocean on North Atlantic climate variability 1871–1999, *J. Clim.*, *16*, 3296–3313.
Terray, L., and C. Cassou (2002), Tropical Atlantic sea surface temperature forcing of quasi-decadal climate variability over the North Atlantic-European region, *J. Clim.*, *15*, 3170–3187.
Venzke, R., M. Allen, R. Sutton, and D. Rowell (1999), The atmospheric response over the North Atlantic to decadal changes in sea surface temperature, *J. Clim.*, *12*, 2562–2584.
Visbeck, M., H. Cullen, G. Krahmann, and N. Naik (1998), An ocean model's response to North Atlantic Oscillation like wind forcing, *Geophys. Res. Lett.*, *25*, 4521–4524.

M. Latif, Leibniz-Institut für Meereswissenschaften, Düsternbrooker Weg 20, D-24105 Kiel, Germany.
H. Pohlmann, Department of Oceanography, Dalhousie University, Halifax, NS, Canada B3H 4J1. (holger.pohlmann@phys.ocean.dal.ca)